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VACUUM SPARKING POTENTIALS UNDER SURGE CONDITIONS

by

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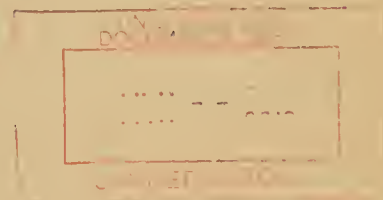
VACUUM SPARKING POTENTIALS UNDER SURGE CONDITIONS

Purpose

It is apparent there will be an increasing number of applications for transient high electric fields produced in vacuum apparatus. The electron injectors for the betatron and synchrotron, any electrostatic deflectors for removing the beam from these instruments or the syncho-cyclotron, and high speed, high intensity X-ray tubes are all examples of this application. Very little information has been published on minimum requirements to prevent sparking under surge conditions in vacuum, [1], [2], [3], [4] although this information would be most useful in designing apparatus of the type just mentioned. The experiments described here were undertaken to provide information to serve as a guide for such design problems.

Experimental Procedure

A metal vacuum system was provided with windows of lead glass. On the face plate of this system a heavy zircon bushing was mounted to carry the high voltage leads and cathode for the spark gap. Also mounted on the face plate was a frame to support the spark gap anode (at ground potential) and a fine screw arrangement to permit motion of the anode for purposes of adjusting the length of the gap. The sparking electrodes themselves were polished hemispheres of 1" radius. The hemispheres were fitted onto cyclinders of the same radius and heaters made of tantalum wire wound on lavite forms were placed inside the cyclinders, (see Figure 1). The heaters served to aid in the outgassing of the sparking surfaces.

To measure the gap length at any time, the power supply was disconnected and replaced by a resistance meter. The gap was then reduced until the resistance meter indicated "short". The number of turns of the fine screw adjustment required for this process indicated the original gap length. Proper care was taken to account for backlash in the screw and gaps could be measured to 0.001 inch without difficulty.

Only one type of voltage wave was used in the measurements, (see Figure 2). This voltage pulse could be applied at varying rates from 10 per second to any slower rate. Usually a repetition rate of about one per second was employed. The generating circuit was of the Marx type and is shown in Figure 3. In all measurements three 0.025 mfd. condensers were connected in series across the vacuum gap. The peak voltage applied

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(1) Loeb "Fundamental Processes of Electric Discharge", p. 471
(2) Beams, Phys. Rev. 44 803 (1933)
(3) Mason, Phys. Rev. 52 126 (1937)
(4) Flowers, Phys. Rev. 48 954 (1935)

to the gap was determined by oscilloscope observations for one charging voltage of the
0.025 mfd. condensers and thereafter the voltmeter across the condensers when connected
in parallel was used to indicate relative peak voltages which would be applied.

Two metals, tungsten and copper, were used separately for both of the vacuum spark
gap electrodes. Although it was not convenient to form one inch radius hemispheres from
tungsten, some were prepared with tungsten inserts of sufficient size that any sparking
always took place between tungsten surfaces. There of course was no trouble in preparing
satisfactory copper hemispheres.

For the outgassing, two methods were employed. By means of the tantalum heating
coils the spark gap electrodes were brought to a dull red temperature and left for several
hours while in vacuum. This procedure was accompanied by difficulties in providing
sufficient water cooling on the vacuum chamber and sufficient shielding around the bush-
ing to avoid coating the insulating surface with a damaging film. The second method of
outgassing was operation of a glow discharge between the spark gap electrodes in a low
pressure argon atmosphere. A discharge of 200 volts at 400 ma was operated for several
hours with each of the spark gap electrodes serving alternately as the cathode of the glow.

Results

For a wave of given peak voltage the critical gap length (minimum gap at which
sparking would not occur) was found to depend on the smoothness, the degree of outgassing,
and probably the material of the electrode surfaces. Figure 4 shows a plot of critical
gap against peak voltage for tungsten and copper electrodes which had been outgassed by
the procedure just described and sparked for a period of many hours. Both materials
show the same characteristic of decreasing critical peak electric field with increasing
peak voltage. The critical peak electric field may be computed by simply dividing the
peak voltage by the corresponding critical gap since the radius of curvature of the hemis-
pheres is always so large compared to the gap itself. Although the curves in Figure 4 are
drawn through experimental points, the actual gap for each peak voltage used was often
indeterminate to within about ± 10%. The experimental points for the curves represent
the center points of these regions.

Consistent results were more difficult to obtain in the case of copper electrodes.
This may have been due to the more frequent changes in surface smoothness of the copper
because of its greater tendency to permit pitting during the sparking measurements. Some
indication of the effect of surface smoothness is given in Figure 5. Curve I in Figure 5
was taken by measuring critical gaps for four different peak voltages beginning with the
lowest. Immediately on completion of measurement of these four points for Curve I, the
same points were repeated in the same order to give Curve II. Before beginning Curve I
the copper electrodes were highly polished and outgassed by heating and by operating in a
glow discharge. With sufficient sparking there eventually is no appreciable further change
in the critical gap. Measurements for this condition were attempted and are those shown
in Figure 4. The same tendency of decreasing critical peak electric field with continued

sparking was noted in the case of tungsten, but the magnitude of the change was consider-ably less than in the case of copper. From the data obtained here, one cannot conclude with certainty that outgassed, polished tungsten surfaces will support greater critical electric fields than similarly treated copper surfaces, although this is probably true.

Outgassing of the electrode surfaces was definitely a great aid in obtaining high critical peak fields. Measurements showed electrodes polished and cleaned with alcohol and acetone would only support critical peak fields between one-half and one-tenth as great as those obtainable with the same electrodes when well outgassed. Also continued improve-ment was noted with application of more drastic outgassing methods. The glow discharge operation in argon had a beneficial effect even after the heat treatment. It is likely that a more extreme outgassing procedure than that used here would lead to attainment of still higher critical peak fields.

Sparking itself never seemed to be an effective means of outgassing although it was almost always true that a few sparks made a slight improvement in the possible critical peak field each time a measurement was made. Another interesting fact was that outgassed electrodes did not require reoutgassing after being exposed to atmospheric air.

The effect of tank pressure on the critical peak fields was investigated. No depend-ency on this pressure was ever observed throughout the range 10^{-5} mm. Hg to 10^{-3} mm. Hg. Argon or air was admitted through a leak valve to bring about the tank pressure variation.

By observing the oscilloscope, it was noted that the spark breakdown occurred when the voltage was rising, if at all. In spite of the fact that the decay time constant for the voltage wave was ten times as great as that for the rise, breakdown essentially always occurred before or at the time peak voltage was attained.

After prolonged sparking, the electrodes took on a characteristic appearance. The cathode showed signs of uniform fine sputtering over the sparking region while the anode was always more deeply marked by a uniform covering of small pits. The cathode, of course, received ordinary ion bombardment. The anode pits were probably the result of local heating by self-focussed electron beams originating from field emission points on the cathode.

Conclusions

For the equilibrium condition after prolonged sparking of outgassed electrodes, the critical peak electric field varied from 1.5 to 0.8 million volts per cm for tungsten and from 1.0 to 0.4 million volts per cm for copper. This variation was a result of peak voltage variation from about 30 to 90 kv.

The most likely explanation of the spark breakdown under these conditions is as fol-lows: Points on the cathode surface where the electric field is at least ten times greater than that calculated from the known voltage and measured gap give rise to small field emission currents. These currents bombard the anode in microscopic areas causing

absorbed gases to be released, possibly some of the base metal to be vaporized, and quanta to be emitted. These quanta can pass back to the cathode and release photoelectrons there which further contribute to the breakdown process in the same way as do the field emission electrons. The vapor released from the anode will give rise to local high pressure regions in which ionization by electrons, and, to a lesser extent photoionization may take place. The ions so produced will then bombard the cathode and be effective in releasing still more electrons and molecules there. Breakdown occurs when these processes are sufficiently cumulative. It is fairly certain that the breakdown observed in these measurements was the result of field emission producing not one but many electrons (or the critical peak field would not undergo consistent change), and that final breakdown depended on production of high local gas pressures (which probably accounts for the gradual decrease of the peak critical field with increasing peak voltage since fewer field emission electrons are required to provide the same local heating if the electron energy is higher).

Finally, in design of an electrode system to support the largest peak fields without sparking, the important consideration appears to be the condition of the electrode surface and not at all the tank pressure for operation below 10^{-3} mm Hg. Outgassing, smoothness and material of the electrode determine these surface conditions.
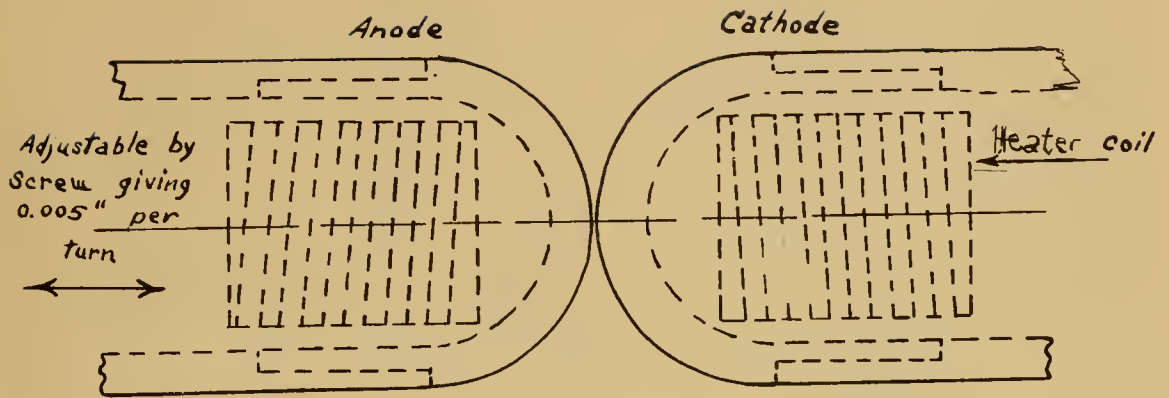
Anode

Cathode

Adjustable by
Screw giving
0.005" per
turn

Heater coil

Figure 1

Time constant
for rise =
~ 3 × 10⁻⁷ sec.
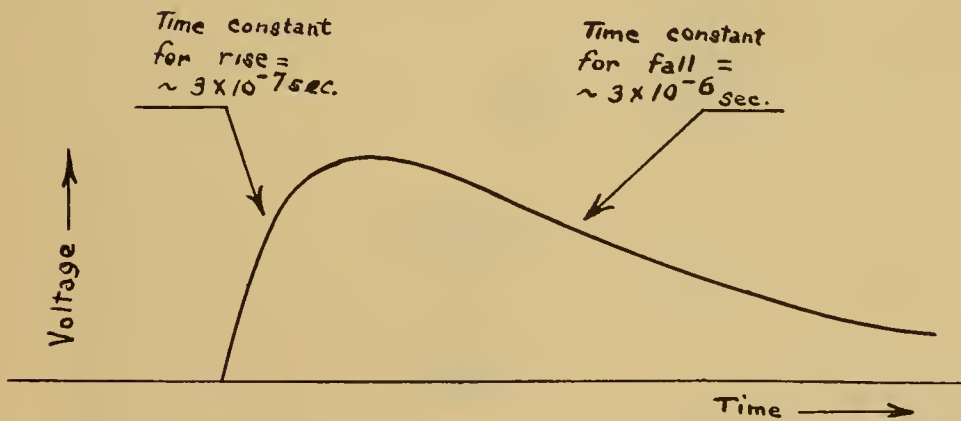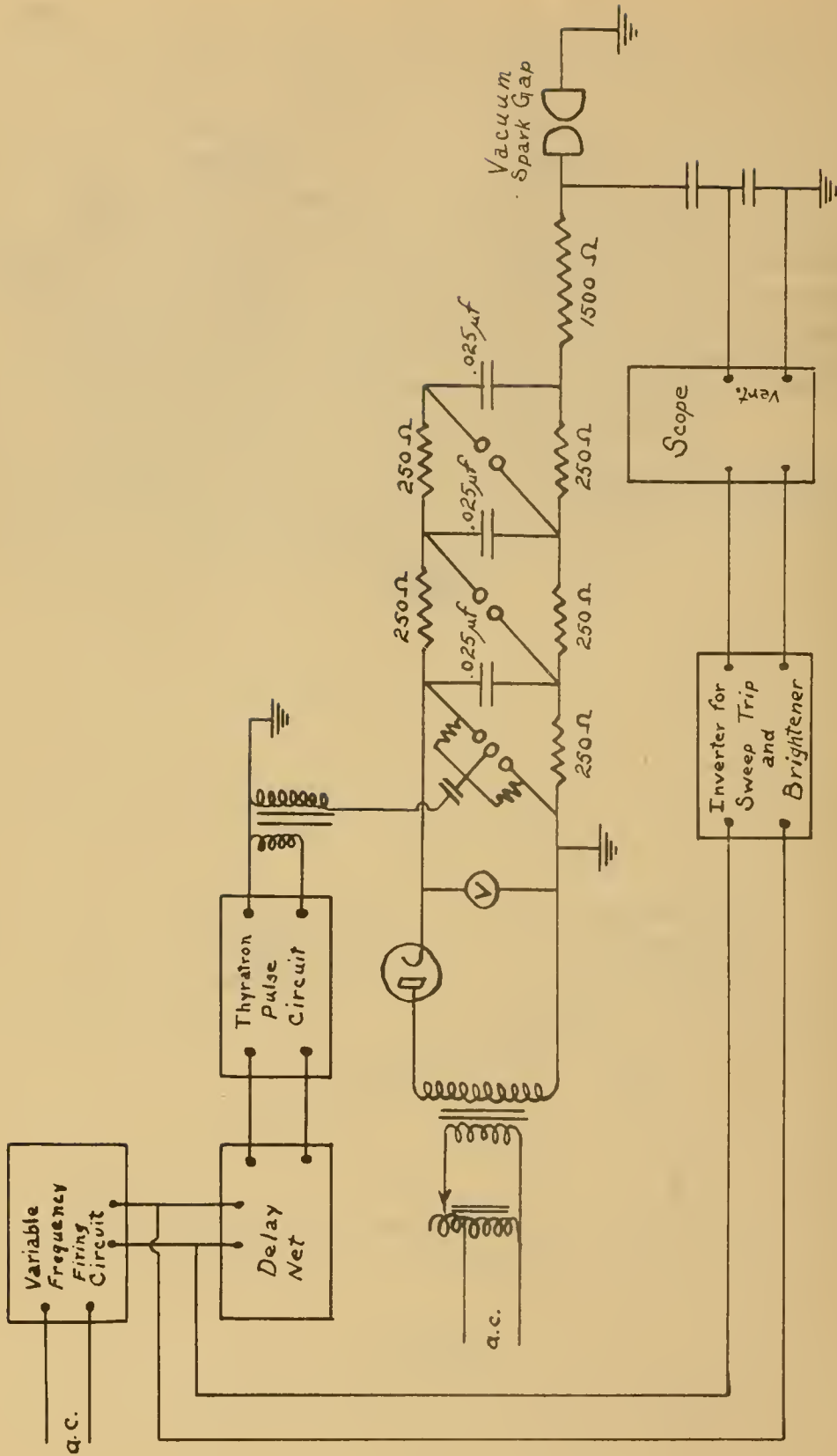
Time constant
for fall =
~ 3 × 10⁻⁶ sec.

Voltage

Time

Figure 2

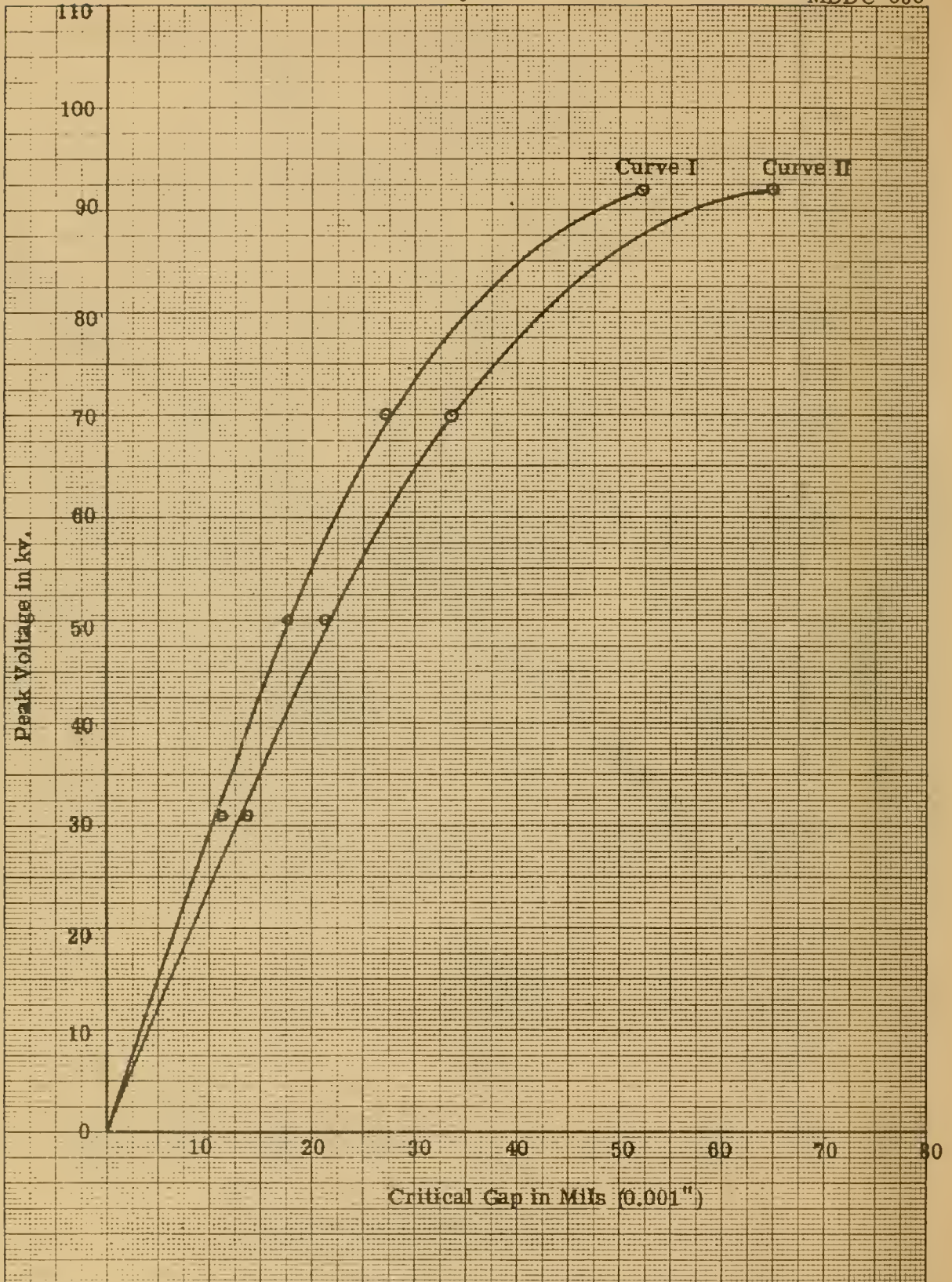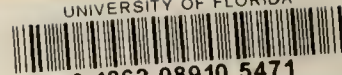Figure 3

All labeled resistors are non-inductive.

Figure 4

Figure 5